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BY
INTERMITTENT FILTRATION.



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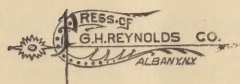
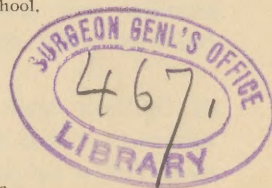


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THE PURIFICATION OF OUR DRINKING SUPPLIES BY INTERMITTENT FILTRATION.*

By HOWARD VAN RENSSELAER, PH. B., M. D.

The question of our water supply here in Albany is so vitally important to all of us, that every member of the community must be interested in the speedy and safe solution of the problem. Much has been said and written during the past few years of the poor condition of our drinking water, and many plans have been advocated, discussed, investigation and abandoned, for obtaining water from other sources than our present supply, i. e., the Hudson river. Now that the latest plan of using the Normanskill creek has been adversely reported by the common council, it seems sure, that the Hudson is to be our main supply for some time at least to come. It was thought timely, therefore, to turn our attention this evening to, and to precipitate debate upon, the difficult problem of purifying the supply which we are compelled to use.

Of the several plans at our disposal the first method to which your attention is directed is one which is of very recent date, is very little known, and involves principles which have just been discovered, and problems which have not yet entirely been elucidated. This means of purifying water is called the *method by intermittent filtration*, and the facts, figures and deductions which are to be presented are based on the recent scientific, carefully-planned, and conscientiously executed experiments undertaken by the State Board of Health of Massachusetts at their experiment station at Lawrence.

*Read before the Medical Society of the County of Albany, at a meeting held February, 1892.

The way this problem came to be attacked arose in the urgent need of some simple and safe plan of purifying the sewage of towns, which were accustomed to drain their effluvia into and pollute the neighboring streams, and which waters were lower down in their course, drawn upon as drinking supplies for the adjacent towns and villages on their banks.

Experiments have been undertaken during the past few years in England, France, and Germany, and to a very limited extent also in this country, with the two-fold purpose of utilizing the sewage as a fertilizing material for growing crops, and also to determine the value and amount of purification of the effluvia through removal of the organic matter, that resulted.

Soils were underdrained, and the water collected from the effluent was examined both chemically and biologically, and was found to be nearly as pure as the average drinking supply in the neighborhood. A number of factors, however, were found to modify both the quantity and quality of the effluent, such as the rain-fall, the quantity of sewage applied, the mode of its application, the nature of the soil, and the character of the growing crops. It was soon found that many soils were capable, under proper conditions, of absorbing and purifying sewage in greater quantity than the crops could stand. This led to investigations, and the plan of applying small quantities of fluids to a soil periodically instead of continuously became known as the *method of purification by intermittent filtration*.

To solve the problems of the maximum purifying capacity of different sands that are found in our valleys, the Massachusetts State Board of Health in 1887 began its experiments. For its purpose a number of filtering tanks were used, each arranged as follows: A tank with an average diameter of seventeen feet, and a depth of six feet, is set with the bottom slightly sloping towards a storing tank. At the bottom of the tank an underdrain fifteen feet in length, of horse-shoe section, about two square inches in area, is set with the open part downwards, and half an inch above the bottom, resting on blocks. The floor is covered with one layer of coarse gravel stones, one inch by two, and this by another of smaller size, on which follow layer after layer of gravel, decreasing in size

to one-eighth of an inch in diameter, and making a thickness of three and a half inches. This fine gravel is covered with very coarse mortar sand three and a half inches deep; above this substratum, which is the same for all the tanks, the filters are filled with different materials, of which we will confine ourselves to two, a fine and a coarse sand, which are the most applicable for our purpose. These sands are similar in size and appearance to the two specimens here presented, one of which was taken from the sand plains, and the other from Tivoli Hollow, both within our city limits.

As the water we drink here at Albany is simply a much diluted sewage, it is advisable to understand what the composition of sewage is. Roughly computed, a fairly strong sewage is composed of 988 parts of water, one part of mineral, and one part of animal and vegetable matter in every thousand parts. If we could remove the mineral and organic [i. e. the animal and vegetable matter] we should have an absolutely pure water; but as the only things which are objectionable are the organic substances, if we can eliminate them, we may then consider the water as pure and safe for drinking purposes.

This organic matter is partly in suspension, and can be removed by a very fine strainer, and partly in solution, and will pass unchanged through the finest pores.

Organic matter is composed principally of complicated combinations of carbon, nitrogen and hydrogen. When such matter decomposes, the carbon for the most part combines with oxygen forming carbonic oxide and passes off at a gas, and most of the nitrogen unites with hydrogen forming ammonia.

In our water as the organic substances decay, part of the carbonic acid escapes, and part goes into solution in the water, the ammonia remains in solution and is partly free and partly in combination with albuminous substances. In sewage there is usually more free than albuminoid ammonia, and as decay proceeds more and more of the albuminoid becomes converted into free ammonia.

In the effluents after water has been intermittently filtered we find the free ammonia has become changed, part of it has entirely disappeared, perhaps escaped as free

nitrogen, but the most of it has become oxidized first into nitrous and nitric acid, and then these acids have combined with potash or soda or lime or other base in the sewage, forming nitrites or nitrates with these bases. So that during the process of intermittent filtration the organic and free ammonia have disappeared from the filtrate, and have become converted into the inorganic nitrates. The albuminoid ammonia much reduced in amount forms, with the exception of the micro-organisms later to be discussed, the only organic impurity.

This conversion of ammonia into nitrates called "Nitrification" is a most important process in the purification of sewage, and was thought at first to be a simple chemical oxidation occurring in the presence of air. Further experiments, however, showed that unless another factor was present, namely, micro-organisms, that these changes did not occur. This was proved by filtering sterilized sewage through sterilized sand, the other conditions being the same. Analysis of the resulting effluent showed as much soluble organic matter as the original contained, and it was only when unsterilized fluids were passed through the filters for a time sufficient for the bacteria present in them to grow, that the purifying changes became manifest.

The value of a filter is shown by the smallness of the quantity of ammonia in the effluent and the greatness of the nitrates. The closer the nitrogen of the nitrates in the effluent approximates the total nitrogen of the sewage, the more thoroughly the organic matter has been oxidized, and its objectionable part been converted into an unobjectionable mineral matter.

The conditions necessary for the purification by nitrification are: Oxygen, organic matter, moisture, an alkali, micro-organisms, and a temperature favorable to the growth of plant life. Where these conditions are present large quantities of organic matter can be converted into inorganic and mineral matter.

Our problem then is to remove not only the suspended organic matter, but also to destroy the albuminous substances in solution. This is more than the ordinary filters to which we are accustomed will do, because they sift out the sus-

pended matter only, and allow all soluble substances to pass through.

Let us suppose first that to a sand filter, such as has been described, as much sewage be continuously applied as will pass through it. What will happen? At first the suspended matter will be mechanically held back in the filter, and the effluent will be somewhat purer than the sewage applied. But after a time the filter becomes saturated with the impurities, can take up no more, and then the applied water and effluent are equally foul. That is what takes place in continuous filtration without the presence of air, when no means are employed to cleanse the sand.

Now with the same filter and sewage, let us vary the manner of application. Instead of applying the sewage continuously, let us flood the surface of the filter, say an inch in depth once to-day, and repeat this daily; and then mark the change, if any, in the composition of the effluent. The inch of fluid applied quickly settles down through the sand, the bottom particles going down about nine inches, while the top-most are just below the surface. Analysis of the contents of these nine inches then is as follows: Two-thirds sand, one-ninth water and two-ninths air. The one inch of water, now distributed through nine inches of sand, is held in thin films between the particles of sand in intimate contact with twice its volume of air.

The following day the applied inch of sewage forces the water and air already in the sand nine inches further down, and occupies the place previously held by it. The same thing happens on each successive day, until at the end of about a week the first applied sewage drips out at the bottom. During all this time this very thin film of water moving over the sand has been bathed with an abundance of air.

The proportion of air, sand and fluid just cited, applies to a coarse, even grained sand. Where a very coarse sand or fine gravel is employed, the water will run through much more quickly, and where a very fine sand is used, it percolates slowly, and a much smaller quantity of fluid must be poured on, or the lower layers of the sand become saturated with water.

Previous to the investigations at Lawrence, very little was

known of the conditions most favorable for the purification of sewage by sand or soil, or the maximum quantity that could be applied, or the intermissions required for producing the purest effluent. Of the great number of experiments undertaken with all kinds of soil and sand, and with varying quantities of water, we will confine ourselves to these which have proved most useful, and which are most applicable to our needs.

Sewage was applied to one of the tanks at the beginning of an unusually severe winter, so that the capacity of the filter was thoroughly tested from the very first. During the cold months of January, February and March, the nitrates were but little greater than those of the sewage, i. e., no nitrification took place within the tank. The ammonias averaged 32 per cent. of those of the sewage. This high proportion of ammonias was due probably to the fact that the upper layers of the sand being frozen, the sewage flowed rapidly through the tank in small areas. As it was, two-thirds of the ammonias were this winter removed by this open sand, with considerable ice in the filter. Although during the winter months no nitrification was going on, yet an important step in the process of purification was taking place. This was the partial conversion of albuminoid to free ammonia, i. e., an oxidation or burning of the albuminoid ammonia into carbonic acid, free ammonia and probably nitrogen gas. This change is as far as it goes a complete destruction of organic matter, although the free ammonia may not be further oxidized into nitric acid and nitrates. Nor is the quantity of the organic matter converted as great as where nitrification exists. It is, however, a partial purification, and the conditions of intermittent filtration are those most favorable to this process of cleansing.

During the second winter the results were much more satisfactory than in the first season. Nitrification which occurred during the summer and autumn now continued, and the sewage applied at 35 degrees F., continued to be well nitrified. From this we can deduce that if the filters be protected from snow they are capable of purifying water efficiently throughout the year.

With the advent of spring a marked change occurred. As soon as the ice melted and the temperature of the effluent rose

to 39 degrees F., nitrification began, and with a rising temperature rapidly increased. The nitrates of the crude sewage averaged less than 0.01 part in 100,000 parts. When nitrification began the nitrates gradually rose till the first week in May, when they reached 3.00 parts, i. e., 300 times the amount in the applied sewage. At that time the temperature of the effluent was 50 degrees F., they then gradually fell. With the exception of this increased activity during the rapidly growing months of April till June, the nitrates in the effluent rise and fall with the rise and fall of the ammonias in the sewage.

The nitrogen which becomes stored in the tank is probably simply a straining out of the sewage of solid particles of organic matter. When nitrification became very active in the spring, it was evident that more nitrogen was coming from the tank than was being applied, making the conclusion necessary that the nitrogenous matter in the filter was being removed. In general nitrification began first and burned most fiercely where the most organic matter had been stored in the tank, and filters started at different seasons of the year, showed that nitrification did not become active until organic matter sufficient to be burned had been stored.

The amount stored in the tank the first year was 26 per cent.; in the second year 8 per cent. The increase was interrupted and the quantity decreased during the period of most active nitrification in the spring. Analysis of the sand of the filter showed that the increase of nitrogen was in the upper foot of the tank; beneath this, during the second year there has been continually less nitrogen than at the end of the first year. In the upper inch of the sand at the end of the second twelve months there was five times as much nitrogen as at the end of the first year, and that below the upper inch there was less nitrogen now stored than at the end of the first season. Examining the effect of the spring nitrification in removing stored nitrogen, we find that in the upper inch it was not reduced, but in every inch below it was removed; the percentage of cleansing increasing with the distance from the top. Hence we may conclude that nitrification is more complete in the lower than in the upper layers of sand. The question then arises whether this material will

not thoroughly cleanse itself of nitrogenous matter, and continue indefinitely an efficient filter, if the upper layer is plowed under once a year.

During the filtration of sewage for these two years, the whole amount has been filtered without removing any sediment, nor any cleansing of the sand, except such cleansing as the process of oxidation or of nitrification produces. This cleansing process has the effect of burning up the organic matter of the sewage, both that which is deposited on the surface, and that which permeates the sand. When the water was applied it disappeared nearly as fast as it was poured on, and the next morning a handful of sand from the dry surface did not have any odor.

Experiments showed that the value of a filter depends on following a definite regime, and requiring every part of it to accomplish its work at regular intervals. The filter thus acts like a living delicate organization, capable of performing what is expected of it, if it is not over-worked; but any change from the normal disarranges the mechanism, and may require weeks before it can adapt itself to the new requirements.

The presence of particular organisms are necessary to aid the work; and with suitable food and proper conditions, they must have time to accumulate before they can perform the best purification with the quantity of sewage received. Changes in quantity or mode of application of the water disorganize the working colony and hinder their best efforts, until they can slowly accommodate themselves to the new conditions.

Of the micro-organisms found in the sewage and effluent, we must distinguish two general classes. 1. The *microscopical organisms*, those which do not have to be cultivated for identification on special media, which are easily studied under the microscope, and which may be plants or animals. 2. The *bacterial organisms*, those which require special method of culture, are studied with difficulty under the microscope, are much more minute than the first class, and consist entirely of plants.

Among the first class, the microscopical organisms, may be mentioned yeast fungi, diatoms and algæ, among the plants; and rhizopods, infusoria, rotifers, etc., among the

animals. Of these the yeast cells are the most abundant, averaging 20,000 to the gallon. Even with yeast, the numbers are insignificant as compared with the second class, the bacterial organisms. These are present in enormous quantities, the average number of 128 analyses of sewage being 708,000 per cubic centimeter.

The question at once arises, what is the fate of the microscopical organisms and bacteria that are applied in the sewage? Are they destroyed in the filter, or do they pass through? If they survive the passage, the filter, although it may convert all the nitrogenous organic matter into simple inorganic salts, is practically worthless; for the danger lies not in the ammonia compounds but in pathogenic bacteria. We will consider first the microscopical organisms, and will trace the yeast fungus, as it is probably typical. Sewage contains large quantities of these germs; and microscopical examination of the surface sand in the tank shows abundant living cells of the yeast fungus. A few inches lower no cells could be detected, and, between the two, they were found dead and partially disintegrated. In the effluent no evidence of this organism has been found. Algæ, living infusoria, etc., are also present on the top of the tank, where they are easily recognized; a few inches below the surface, however, no such organisms are ordinarily recognized. Normally they appear to perish in the tank. There are, however, some forms which are found both in the sewage and effluent, but they probably increase in the underdrains themselves.

To determine if the underdrains and gravel contained more micro-organisms than the effluent flowing through them, ten gallons of sterilized water was forced back into the underdrains and allowed to run out rapidly. The number of organisms in samples of 200 c. c. were about fifty for the first two washings, and from three to seven for the third and fourth washings. As the water forced into the underdrains contained no living forms, and as when rapidly flowing out it bore considerable numbers at first, and when repeatedly washed the numbers very rapidly decreased, it indicates that the organisms grow and increase in the underdrains, but does not prove that an exceedingly small percentage of some of the kinds applied with the sewage

may not come through. It may be that the spores or eggs of some of the few organisms found in the effluent are able to survive the passage of the sand and develop in the underdrains, when it is impossible for the mature organic beings to pass through, but as the actual number of microscopic forms found in the effluent is much smaller than in ordinary drinking waters, it is evident that the conditions met with in the filter are very unfavorable for the passage and development of such germs.

The second class of organisms, the bacteria, are found everywhere; they are present in enormous quantities in sewage, to a much less extent in all waters, and also in the air. Bacteria are, according to their form, divided into two great classes; minute spherical bodies called micrococci, and the elongated rodlike bacteria, which have been named bacilli. It is worthy of remark that cocci rarely occur in sewage or effluents, which confirms the statement made some time ago by P. F. Frankland, that cocci usually predominate in the air, while bacilli are the prevailing forms in water.

Immediately after sewage was applied for the first time to any filter very large numbers of bacteria came through; then after sewage had taken full possession of the tank they rapidly decreased in the effluent, and after nitrification had once set in they decreased to a small fraction of one per cent of the number in the sewage. The average number of bacteria that were found in the effluent for the past year and a half was about two thousand per c. c. and for three months of the time, when nitrification was most active, the number averaged but eighty, while at the same time the quantity applied in the sewage was more than a million.

The number of bacteria in the effluent in the tanks of coarse sand varied much from day to day, and also from hour to hour, depending on the rate of flow. It was found that an hour after sewage had been applied to the filter the water at the outlet would increase for an hour or two and then decrease. Samples of the effluent were collected just before the application of sewage, and continued at intervals for some hours after. It was shown that not long after the application of the water that the number of bacteria discharge per unit volume, is many times greater

than at any other time. And as this coincides in a general way with the period of rapid flow, it follows that a majority of all the bacteria discharged during the day escape in a comparatively limited time, and a sample taken at this time differs widely from one taken before the maximum flow, or long after.

Experiments were instituted to determine whether the increased numbers in the effluent present during the greater flow, were due to the washing off of bacteria that had accumulated or grown in the underdrains, or whether they were coming through the sand in greater numbers at that time.

To determine this, when the water was slowly trickling through the tank the outlet pipe was closed for several hours. The water was then drawn off with varying velocities. When it was drawn slowly, it contained very few bacteria, but when it flowed at a rapid rate the number greatly increased, showing that some of the germs were washed from the underdrains during the rapid flow; but this increase was not as great as when the effluent was coming rapidly through the sand at the time of its maximum volume. When the water was passing through the tank at its great speed, the number of bacteria had increased from about 150 to 10,000. The increased flow from the underdrains, on the other hand, by damming it and allowing it to flow out rapidly, raised the number by a few hundred only. From this it follows that the augmentation is due to more bacteria coming down through the sand with the rapid flow, rather than a washing off of individuals from the undergrains and gravel. The reason seems to be that with coarse sands, the air space, after the filter has drained for a day, is about twice that occupied by water. When sewage is now applied in large quantity, the air passages being quite large, it flows into them rapidly, and passes some of the water held in the more minute interstices; and a small percentage of this sewage reaches the outlet within an hour or two, carrying with it a considerable fraction of the contained bacteria.

In order to determine whether, under the ordinary conditions of intermittent filtration, bacteria pass through the filter, the following experiment was tried. A species of bacteria very easy to recognize called *Bacillus Prodigiosus*, which had never been observed in the sewage or effluents and

is not native to this country, was chosen. This germ was carefully cultivated and then added in enormous quantities to the charge of sewage. In the coarser sands an extremely small number came through, which showed that most of those applied perished in the filter. Nor were any found at any later date, although hundreds of examinations were made of the effluent and the sand in the tank. The conclusion is inevitable that it speedily died out. When applied to somewhat finer sand filters, none of the germs came through. While, however, a foreign species of bacteria, if applied in vast numbers to coarse sand tanks, may escape in the effluent in exceedingly diminished numbers, yet there is no direct evidence that an indigenous species may not survive the passage of the tanks. The direct evidence thus far obtained shows that if any species does come through, it is only in vastly diminished numbers.

Besides the bacteria found in the sands in the filters there is a considerable quantity of brown flakes of amorphous matter called mycoderma, or zooglœa. This zooglœa is, doubtless, composed of groups or families of living bacteria, the cells of which have been converted into an intercellular substance of a gelatinous character. They are produced, probably, by the swelling of the outer part of the cell-walls of the bacteria, and are believed to be closely related to cellulose in composition. They are therefore comparatively indestructible. It may be owing to their presence that a continuous filter clogs so rapidly with sewage, while their destruction by the oxidations of intermittent filtration is probably an essential condition of the successful operation of the latter. This zooglœa is constant and characteristic in all the tanks. It is the only organic substance occurring from the top to the bottom of the filters. It cannot be regarded as an accidental accumulation of debris, as it is uniform in character, and is attached to the sand-grains as if it had been formed there, rather than if it had been accidentally detained. It is found clinging to the sand in large quantities, sometimes nearly every grain being fringed with it. It is believed that the bacteria in this stage are alive and active, though they do not grow on gelatine plates; it is also thought that a sand filter is ineffective until this zooglœa has begun to form. The work done by these

masses in the mature filters is very great, and disproportionate to the alterations in the zoogloea themselves, just as in the fermentation by yeast cells, a small amount of yeast is capable of producing great chemical changes.

In examining biologically the different layers of sand in a tank, it was found that the greatest number of bacteria were near the surface and decreased towards the bottom. The species that liquify gelatine were for the most part near the top, and seemed to die before reaching the lower layers of the filter.

From examinations of sand at different times it seems probable that large numbers of bacteria are stored in the tank, although at the same time but few may be found in the effluent, and indicates that the bacteria distributed throughout the sand are not moving from top to bottom with the liquids, but are adapted to live there, and are permanently attached to the sand, and are only occasionally dislodged by the passing fluid. This suggestion is supported by the fact that once, when the bacteria distributed throughout the sand were nearly all of one species, none of this particular kind were found in the effluent.

Experiments have shown that with these coarse sands that it is mechanically possible for large percentages of bacteria to pass through the filter alive, so that when we find that during intermittent filtration the number passing out is very far below these percentages, we must conclude that some other conditions besides the mechanical one is inimical to their survival.

We have seen that when sewage was first applied to a tank, and meeting in the sand abundance of oxygen, and carrying down oxygen with it, and there being at that time, no destruction of organic matter, that from 5 to 40 per cent of the bacteria passed out alive. But just as soon as sewage permeated the whole tank, and the oxygen taken in for the most part combined with the carbon of the organic matter, to form carbon dioxide, there was only sufficient oxygen remaining to support a little over one per cent of the bacteria during their passage, and finally that after nitrification had set in that the number fell much below one per cent.

From this we may conclude that after the filter is mature

and nitrification is established, the conditions present are extremely unfavorable to the life of organisms, for although there appears to be an abundance of food, the bacteria do not decrease with the decrease of the sum of ammonias, but with the completeness of nitrification. When nitric acid and nitrates were being formed by the burning up of the nitrogen in the organic matter, and when this oxidation was most complete the number of bacteria were the fewest. So that their destruction may be due partly to the process of oxidation depriving them of oxygen, and also perhaps their own oxidation, i. e., their being burned.

In one of the tanks, city water was filtered for two years at the rate of 300,000 gallons per day. Analysis of this water showed that but five per cent. of the total nitrogen was in suspension and could be strained out by the finest filter-paper, and the remaining ninety-five per cent was in solution. During the first three months of filtration sixty-six per cent. of the nitrogen in solution was retained by the filtering material. Just how the sand retains the soluble nitrogenous matter is not clear, but the fact has been shown in all the filtering tanks. When nitrification commenced more nitrogen came away in the effluent than was applied, nearly equalling the amount stored during the previous three months. At the end of two months all the stored nitrogen was burned up, and there being but little left to burn, nitrification ceased for three months, when sufficient matter having again accumulated, it lighted up, and continued throughout the second year. At the end of this time there was no more organic matter stored in the tank, than there was at the beginning, and after being used continuously for two years, without any disturbance of material, or cleaning of the surface, except that of the cleansing by nitrification, that the filter is in better condition for filtration than at the commencement, and shows that it may be continued indefinitely. The filtered water compares favorably with excellent unpolluted ground water. Its color is entirely removed by filtration; and the effluent is clear, bright and colorless.

Of the microscopic organisms, in four examinations only out of twenty were any individuals found, and these species live and grow in places like the underdrains, and probably

those detected did not come through the tank. So that we can conclude that the microscopical organisms are entirely removed by the filter.

As to the bacteria, the number found in the effluent varied but little, but was smaller the second year than the first, averaging about eight per cubic centimeter. With this small number the conditions for their successful passage through the filter or growth in the underdrains is unfavorable. To prove that bacteria do grow in the underdrains, the pipe was washed out with a sterilized sponge. At this time the average number in the effluent was six per cubic centimeter. When the pipe was wiped a foot at a time, and water squeezed from the sponge, the average number varied from 212 per c. c. for the first foot, to 5,880 to the sixth, and averaging for each foot 1,570. These numbers growing in the pipe and underdrains are sufficient to supply the small numbers found in the effluent.

To review briefly what we have discussed, we have seen that with coarse sands the effluent is colorless and generally clear, and contains about one-thousandth of the number of bacteria applied, that from 97 to 99 per cent. of the organic matter is removed, but that an hour or so after applying fluids there is liable to be a temporary decrease in purification and increase in bacteria. That the mechanical separation of part of the organic matter is but an incident, and that the important condition is a slow motion of thin films of water over particles of sand, with sufficient spaces between them, to allow continual contact of air with the films of fluid. That the microscopical organisms normally perish in the upper two inches of sand; and that the presence of bacteria in the upper layers of the tank, where the solid living organic matter is being destroyed, indicates that the disintegration may be the result of fermentation produced by these germs.

A most important feature of intermittent filtration is the nearly complete removal of sewage bacteria in the sand, which shows that the filters not only separate, but also thoroughly disintegrate the greater part of the organisms applied in the water; and that this destruction is most active when nitrification is most complete.

The simplest theory of the action of a filter is, that it is mechanical, that is, that it acts as a strainer. Such a filter, however, soon chokes, unless it is cleansed. An intermittent filter, on the other hand, not only does not choke, but is self-cleansing. The organic matter in solution becomes changed, and the suspended matter accumulates for a short time only; both appear in the effluent no longer as organic material, but as inorganic salts. Mechanical process alone cannot produce

such alterations, and the conditions are such that a mechanical hypothesis can be excluded.

The next simplest theory is the chemical one. That such chemical decompositions do take place is evident, the changes effected resembling the burning by fire. But this theory alone is not sufficient to explain all the facts; and an additional element, micro-organisms, must also be present. So that the chemical hypothesis has given way to one essentially vital, or biological. The important features of intermittent filtration so far established are: "Mature filters give the best results. A distinct regimen is essential to success. Free oxygen is indispensable. Water is best purified when held in thin films between the sand grains. The period of greatest destruction of bacteria corresponds with the time of most active nitrification."

The points in favor of purification of water by intermittent filtration are. No chemical substances need to be added to the water. The filters are self-cleansing and require no care. When once set up there is almost no further expense. They are indestructible. The effluent is far purer, both chemically and biologically than any method by chemical precipitation.

That although this method is not perfect, yet it gives a drinking water purer and safer than by any other process.

EXPLANATION OF THE PLATE.

The upper heavy line represents the sum of Ammonias as given in parts per 100,000 of unfiltered sewage.

The dotted line represents the nitrates in the effluent. In crude sewage the nitrates are practically nil, and are not represented in the plate. It will be observed that during the first three winter months, that there was practically no nitrification, the amount of nitrates being but little above zero, and that in April it suddenly lighted up, and burned with great vigor during April and May, and that in the latter part of May and June it rapidly decreased and remained low for a time, and after this, rose and fell in general with the rise and fall of the sum of Ammonias in the crude sewage, until in the following spring nitrification again became more active and continued until the stored nitrogen in the tank was for the most part consumed, when it again followed the fluctuations of the sum of Ammonias.

The lower light line represents the sum of the Ammonias in the effluent. At first before nitrification commenced the Ammonias were comparatively high; with the beginning of the burning process, they at once fell and constantly remained very low, less than one quarter of one part per 100,000 parts.

The plottings are calculated from the diagram of tank 1 in the Report of the State Board of Health of Massachusetts for 1890. Each point represents the average of about eight observations each, from the first half and the last half of every month.

